

## DESIGN AND ANALYSIS OF HORN ANTENNA AND ITS ARRAYS AT C – BAND

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### ABSTRACT

Wireless communication is the prime area for research now a day in the world. In wireless communication systems Antenna is a prime element for both transmission and reception. Antenna is a main source of electromagnetic energy. It is a transducer which converts electrical energy in to electromagnetic energy.

At microwave frequencies applications, because of the ruggedness Horn Antennas are preferred, it gives high gain values. In the present work an attempt has been made to design a pyramidal horn antenna at c- band. The design was simulated using Matlab. The characteristics of horn antenna are depending upon its aperture lengths and how the horn antenna characteristics like beam width, side lobe levels, gain are varied with respect to their lengths are also studied.

Array antenna distributes its electromagnetic energy in to free space in different directions. The gain of a single antenna element is not sufficient for most applications. Arrays are often used to increase the gain, directivity and reduce the beam width. Horn linear and planar array patterns are plotted in the present work in both rectangular and polar forms. Array antenna radiation patterns are extremely useful in both airborne as well as ground based applications.

**KEYWORDS:** Horn Antenna, Array Antennas, Pattern Multiplication, Wireless Communication and Radar Systems

### INTRODUCTION

An Antenna is a metallic device with transmitting and receiving the electromagnetic signals according to IEEE standard definition in free space.

The horn antenna is used in the transmission and reception of RF microwave signals, and the antenna is normally used in conjunction with waveguide feeds. A horn antenna form of antenna that consists of a flared waveguide which is shaped like a horn and it has the effect that it enables a transition between the waveguide and free space and it also directs radio waves in a beam [1].

The importance of Horn Antenna is its providing high gain. When the aperture size of the horn antenna and the taper of the horn antenna is large it provide high gain and directivity [1-10]. One of the first horn antennas was constructed in 1897 by Indian radio researches Jag dish Chandra Bose in his pioneering experiments with microwaves. In the 1930's the first experimental research (south worth and Barrow, 1936) and theoretical analysis (Barrow and Chu, 1939) of horns as antennas was done. The development of radar in World War 2 stimulated horn research to design feed horns for radar antennas. Horn antenna has a standard Rectangular waveguide closed at one end and the other end is flared which is in the pyramidal shape as shown in figure – 1. The waveguide is excited by a coaxial feed, and the waves are travelling in the waveguide and radiates from the aperture side of the antenna. The radiated wave is narrow beam [5]. Mainly horn

antenna is kept at outside. These are also used in satellites [2].

### Types of Horn Antenna

There are different types of Horn antennas available like pyramidal, sectoral, conical, exponential and corrugated Horn antennas. The pyramidal horn antenna takes on a rectangular shape – the cross section through the antenna is rectangular, as is the end of the antenna. It is normally used with rectangular waveguide.

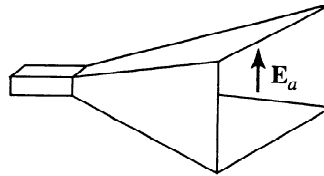


Figure 1: Horn Antenna

### DESIGN FORMULATION OF HORN ANTENNA

The design of a Horn Antenna at a given frequency is given below. From the figure 2 the standard Rectangular wave guide having the width  $a$  and length  $b$ , at the end of the open ended Rectangular wave guide. The mouth is flared in  $a_1$  and  $b_1$ .

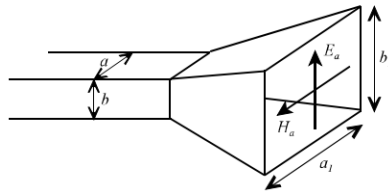


Figure 2: Pyramidal Horn Antenna with Dimensions

$$a_1 = 5.5\lambda \quad (1)$$

$$b_1 = 2.75\lambda \quad (2)$$

$$a = 0.5\lambda \quad (3)$$

$$b = 0.25\lambda \quad (4)$$

$$\rho_1 = \rho_2 = 6\lambda \quad (5)$$

$$c = 3 \times 10^8 \text{ m/sec} \quad f = 5 \text{ GHz} \quad \lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/sec}}{5 \text{ GHz}} = 6 \text{ cms}$$

By using (1) to (5) values the slant lengths and Aperture lengths are calculated below:

$$L_E = \frac{b_1^2}{8\lambda\rho_1} = 0.157 \text{ cms} \quad (6)$$

$$L_H = \frac{a_1^2}{8\lambda\rho_2} = 0.63\text{cms} \quad (7)$$

$$A_E = \sqrt{2\lambda}L_E = 0.54\text{cms} \quad (8)$$

$$A_H = \sqrt{3\lambda}L_H = 2.67\text{cms} \quad (9)$$

The directivity (in dB) of a pyramidal horn, over isotropic, can also be approximated by,

$$D_p(\text{dB}) = 10 \left[ 1.008 + \log_{10} \left( \frac{a_1 b_1}{\lambda^2} \right) \right] - (L_E + L_H) = 21 \text{ dB}$$

The gain of a pyramidal horn,

$$G = \frac{1}{2} \frac{4\pi}{\lambda^2} (a_1 b_1) = 95 \text{ dB}$$

### Radiation Pattern of Horn Antenna

For a given resonant frequency, the Radiation pattern of Horn antenna is given by[7-8]

$$X = \frac{a}{\lambda} \sin \theta \cos \phi \quad (10)$$

$$Y = \frac{b}{\lambda} \sin \theta \sin \phi \quad (11)$$

$$E_\phi(\theta) = \pi^2 \cos \theta \frac{\cos \left( \frac{\pi a}{\lambda} \sin \theta \right)}{\pi^2 - 4 \left( \frac{\pi a}{\lambda} \sin \theta \right)^2} \quad (12)$$

$$E_\theta(\theta) = \frac{\sin \left( \frac{\pi b}{\lambda} \sin \theta \right)}{\frac{\pi b}{\lambda} \sin \theta} \quad (13)$$

### Linear Arrays

The Array Factor (AF) is independent of the antenna type assuming all of the elements are identical. Thus, isotropic radiators may be utilized in the derivation of the array factor to simplify the algebra[6]. The field of an isotropic radiator located at the origin may be written as (assuming  $\theta$  polarization).

$$E_\theta = I_o \frac{e^{-jkr}}{4\pi r} \quad (14)$$

We assume that the elements of the array are uniformly spaced with a separation distance  $d$ .

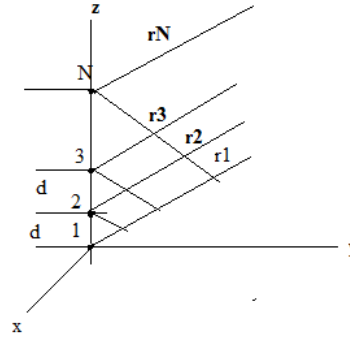


Figure 3: N-Element Linear Array

In the far field of the array,

$$\begin{aligned} r_1 &= r \\ r_2 &\approx r - d \cos \theta \\ r_3 &\approx r - 2d \cos \theta \\ &\vdots \\ r_N &\approx r - (N-1)d \cos \theta \end{aligned}$$

The far fields of the individual array elements are

$$\begin{aligned} E_{\theta 1} &\approx I_o \frac{e^{-jkr}}{4\pi r} = E_o \\ E_{\theta 2} &\approx I_o e^{j\phi_2} \frac{e^{-jkr(r-d \cos \theta)}}{4\pi r} = E_o e^{j(\phi_2 + kd \cos \theta)} \\ E_{\theta 3} &\approx I_o e^{j\phi_3} \frac{e^{-jkr(r-2d \cos \theta)}}{4\pi r} = E_o e^{j(\phi_3 + 2kd \cos \theta)} \\ &\vdots \\ E_{\theta N} &\approx I_o e^{j\phi_N} \frac{e^{-jkr[r-(N-1)d \cos \theta]}}{4\pi r} = E_o e^{j[\phi_N + (N-1)kd \cos \theta]} \end{aligned}$$

The overall array far field is found using superposition

$$\begin{aligned} E_{\theta} &= E_{\theta 1} + E_{\theta 2} + E_{\theta 3} + \dots + E_{\theta N} \\ &= E_o \left[ 1 + e^{j(\phi_2 + kd \cos \theta)} + e^{j(\phi_3 + 2kd \cos \theta)} + \dots + e^{j(\phi_N + (N-1)kd \cos \theta)} \right] \\ &= E_o [AF] \\ AF &= 1 + e^{j(\phi_2 + kd \cos \theta)} + e^{j(\phi_3 + 2kd \cos \theta)} + \dots \end{aligned}$$

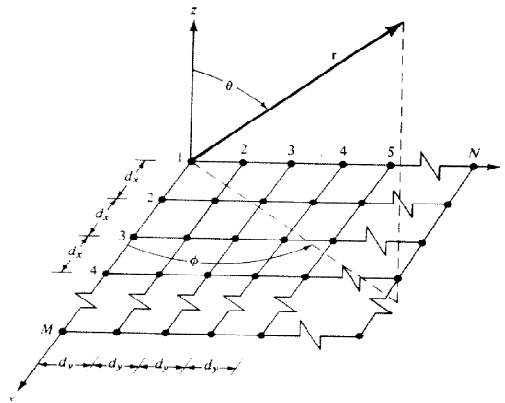
From the above, The normalized uniformly Linear Array Factor is given by,

$$AF_n = \frac{\sin\left(\frac{N\psi}{2}\right)}{N \sin\left(\frac{\psi}{2}\right)} \quad (15)$$

Here  $N$  = number of element;  $\psi = \beta d \cos \theta + \alpha$ ;  $d$ =spacing between the elements;  $\beta$ = wave number.

### Planar Arrays

Planar array provide directional beams, symmetrical patterns with low side lobes, much higher directivity (narrow main beam) than that of their individual element. In principle, they can point the main beam toward any direction [4].



**Figure 4: Rectangular Planar Array**

The Array Factor of a linear array of  $M$  elements along the  $x$ -axis is:

$$AF_{x1} = \sum_{m=1}^M I_{m1} e^{j(m-1)(kd_x \sin \theta \cos \phi + \beta_x)}$$

Then, the array factor of the entire  $M \times N$  array is:

$$AF = \sum_{n=1}^N I_{1n} \left[ \sum_{m=1}^M I_{m1} e^{j(m-1)(kd_x \sin \theta \cos \phi + \beta_x)} \right] \cdot e^{j(n-1)(kd_y \sin \theta \sin \phi + \beta_y)}$$

The normalized array factor is obtained as:

$$AF_n(\theta, \phi) = \left[ \frac{1}{M} \frac{\sin\left(\frac{M\psi_x}{2}\right)}{\sin\left(\frac{\psi_x}{2}\right)} \right] \cdot \left[ \frac{1}{N} \frac{\sin\left(\frac{N\psi_y}{2}\right)}{\sin\left(\frac{\psi_y}{2}\right)} \right] \quad (16)$$

The major lobe (principal maximum) and grating lobes of the terms:

$$S_{xM} = \frac{1}{M} \frac{\sin\left(M \frac{\psi_x}{2}\right)}{\sin\left(\frac{\psi_x}{2}\right)} \quad \sin_{yN} = \frac{1}{N} \frac{\sin\left(N \frac{\psi_y}{2}\right)}{\sin\left(\frac{\psi_y}{2}\right)}$$

### Pattern Multiplication

Given an antenna array of identical elements, the radiation pattern of the antenna array may be found according to the pattern multiplication theorem [10].

Pattern Multiplication Theorem:

$$\text{Total field pattern} = \text{Element Pattern} * \text{Array Factor} \quad (19)$$

$$\text{Total Pattern: } \overline{f}(\theta, \phi) = \sum_{n=1}^N w_n \overline{f}_n(\theta, \phi) e^{jk\psi_n(\theta, \phi)}$$

$$\psi_n(\theta, \phi) = x_n \sin \theta \cos \phi + y_n \sin \theta \sin \phi + z_n \cos \theta$$

$$\overline{f}(\theta, \phi) = \overline{f}_i(\theta, \phi) \sum_{n=1}^N e^{jk\psi_n(\theta, \phi)w_n} \quad (20)$$

The above equation is the Pattern multiplication.

Where

$\overline{f}_i(\theta, \phi)$  - Element factor

$$\sum_{n=1}^N e^{jk\psi_n(\theta, \phi)w_n} \text{ - Array Factor}$$

The radiation pattern of a horn array antenna is derived from the above pattern multiplication.

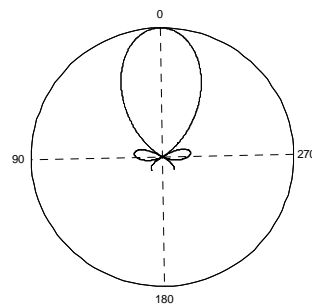
$$E_{TH} = \text{Horn antenna field pattern} \times \text{array factor} \quad (21)$$

### RESULTS

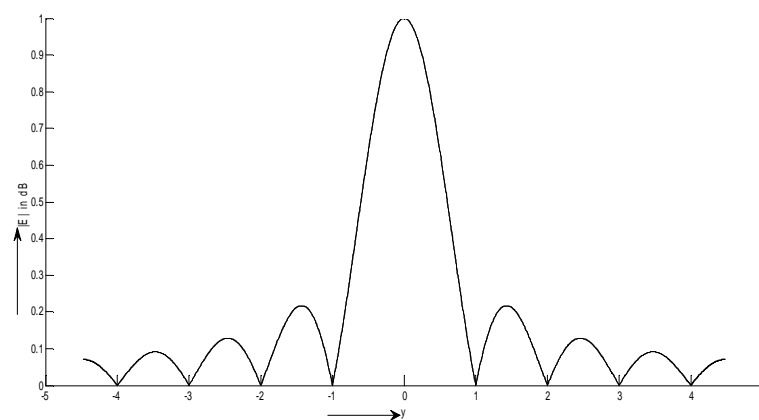
The results are obtained by using the equations 1 to 9 at the resonant frequency. The horn antenna width and length are calculated and obtained the values  $a=0.5\lambda$ ,  $b=0.25\lambda$ . The radiation patterns are obtained in H-plane using equation 13. The results are presented from figures 7 to 8 in both polar and rectangular form.

The horn arrays in both linear using equation 15 and planar array equation 17, 18 systems are also designed by using the pattern multiplication principle equation 19, 20. The results are presented from figures 9 to 28. The radiation patterns are drawn for  $N=5, 10, 20, 40, 80$ . These are compared with the isotropic radiators and coming with good agreement

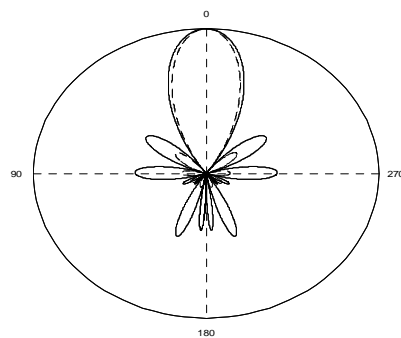
in both linear and planar array system. These are useful in wireless communication and Radar systems.



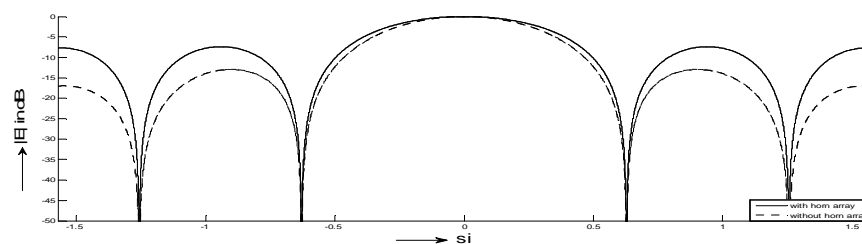
**Figure 5: Polar Plot of Pyramidal in H-plane Horn Antenna**



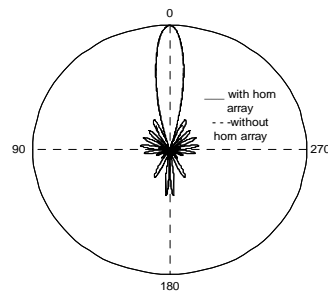
**Figure 6: Rectangular Plot of Pyramidal in H-plane Horn Antenna**



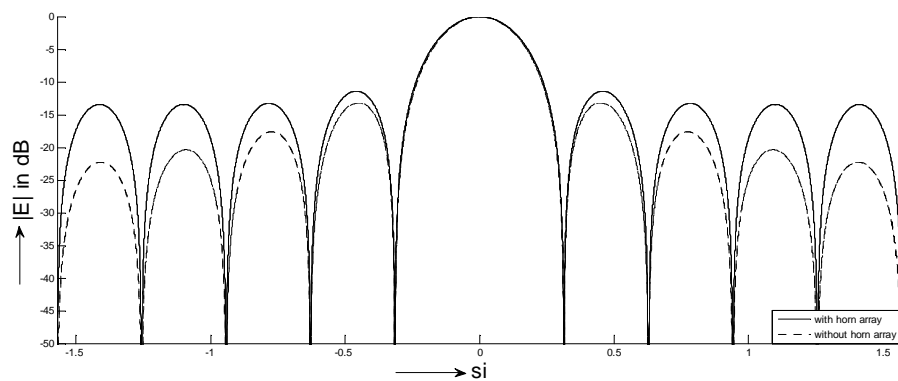
**Figure 7: Radiation Pattern of Horn Linear Array in Polar form for N=5 Elements**



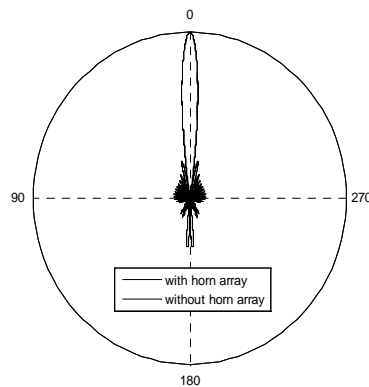
**Figure 8: Radiation Pattern of Horn Linear Array in Rectangular form for N=5 Elements**



**Figure 9: Radiation Pattern of Horn Linear Array in Polar form for N=10 Elements**



**Figure 10: Radiation Pattern of Horn Linear Array in Rectangular form for N=10 Elements**



**Figure 11: Radiation Pattern of Horn Linear Array in Polar form for N=20 Elements**



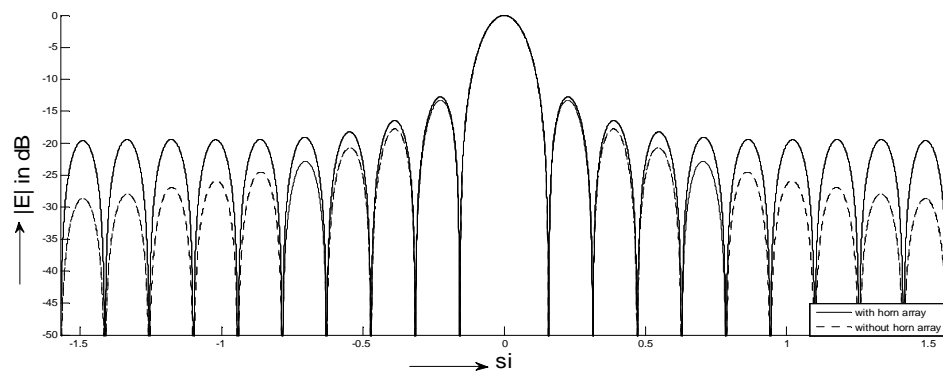


Figure 12: Radiation pattern of Horn Linear Array in Rectangular form for N=20 Elements

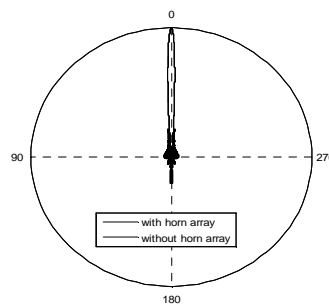


Figure 13: Radiation Pattern of Horn Linear Array in Polar form for N=40 Elements

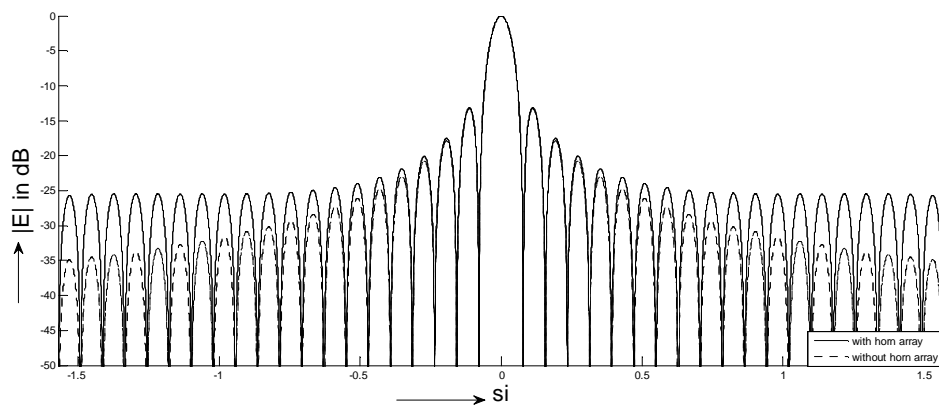


Figure 14: Radiation Pattern of Horn Linear Array in Rectangular form for N=40 Elements

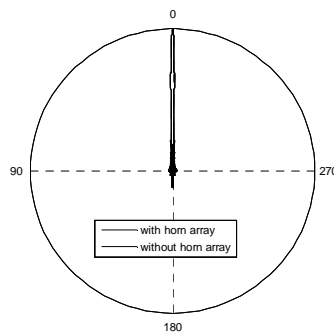
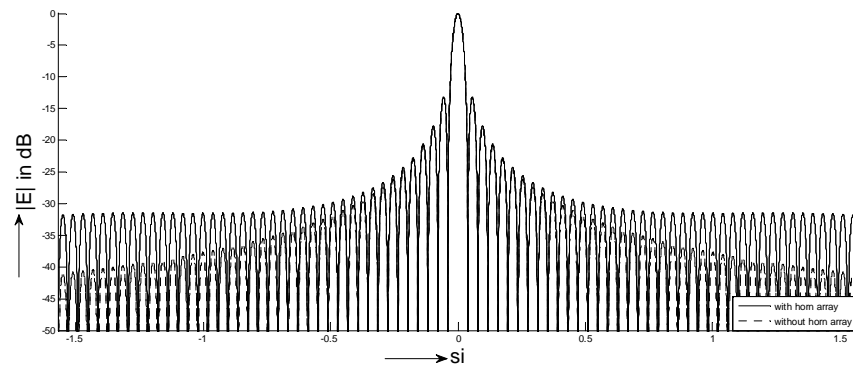
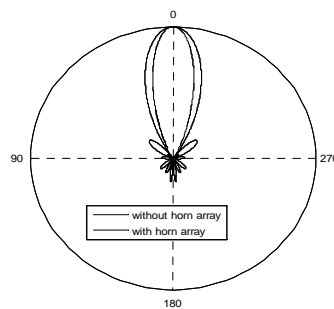


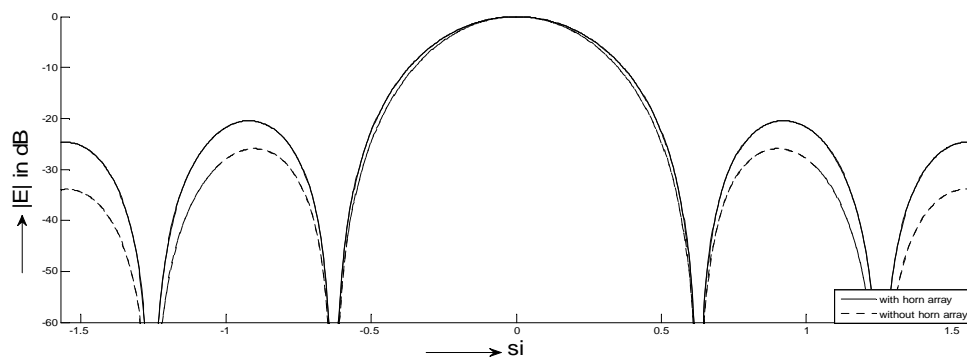
Figure 15: Radiation Pattern of Horn Linear Array in Polar form for N=80 Elements



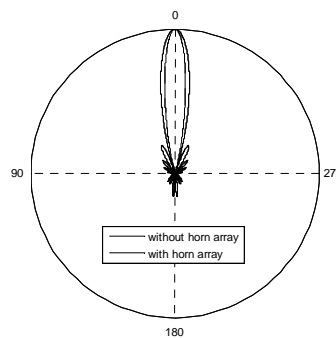
**Figure 16: Radiation Pattern of Horn Linear Array in Rectangular form for N=80 Elements**



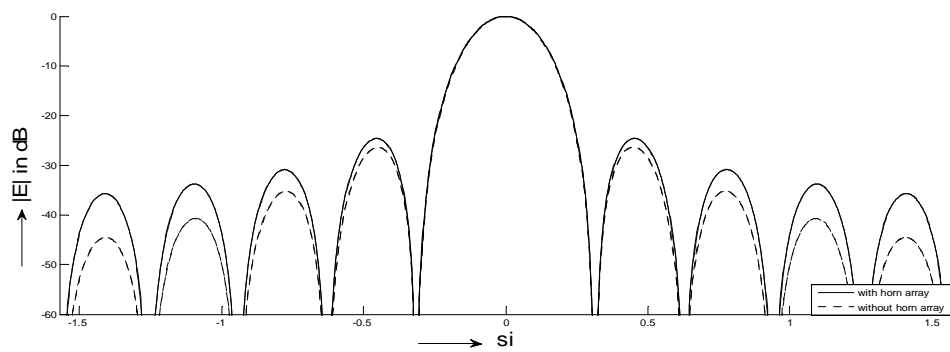
**Figure 17: Radiation Pattern of Horn Planar Array in Polar form for N=M=5 Elements**



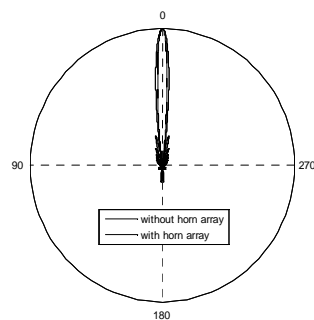
**Figure 18: Radiation Pattern of Horn Planar Array in Rectangular form for N=M=5 Elements**



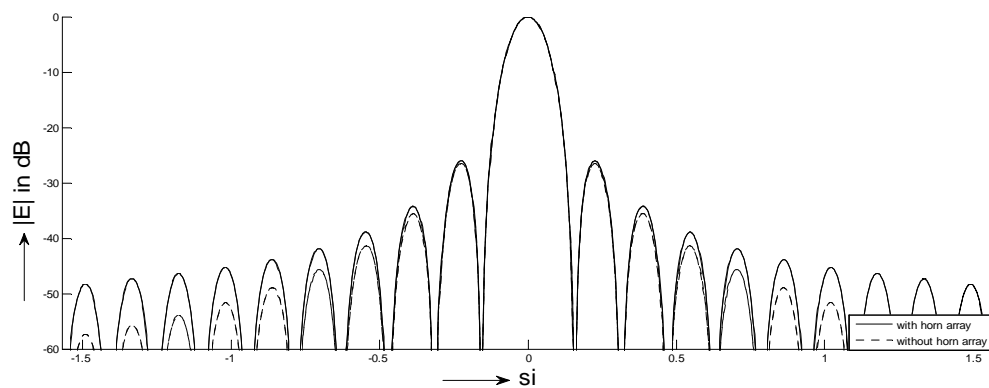
**Figure 19: Radiation Pattern of Horn Planar Array in Polar form for N=M=10 Elements**



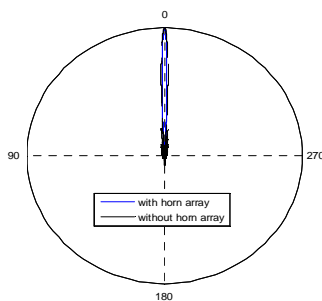
**Figure 20: Radiation Pattern of Horn Planar Array in Rectangular form for N=M=10 Elements**



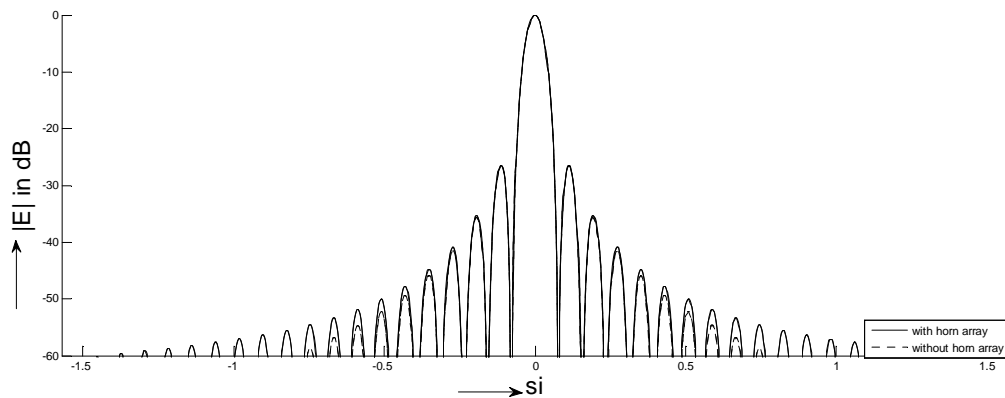
**Figure 21: Radiation Pattern of Horn Planar Array in Polar form for N=M=20 Elements**



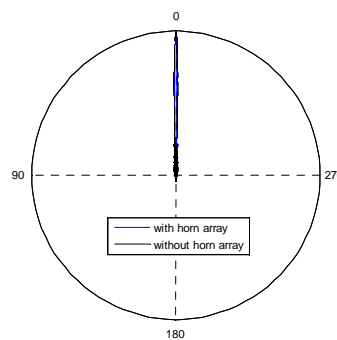
**Figure 22: Radiation Pattern of Horn Planar Array in Rectangular form for N=M=20 Elements**



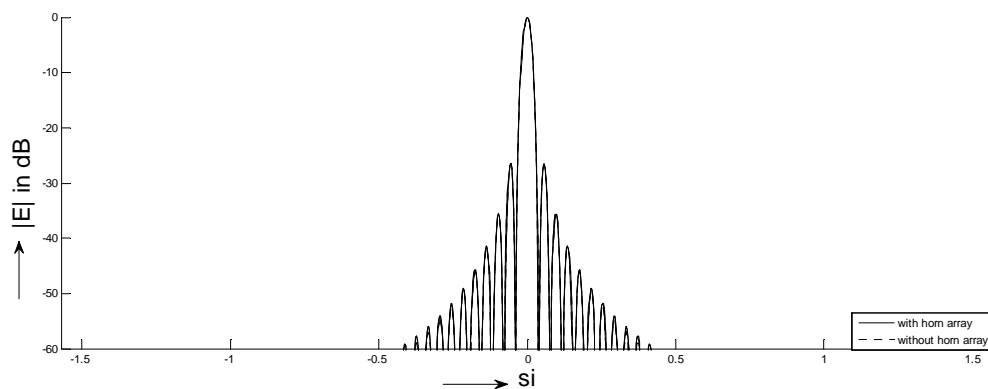
**Figure 23: Radiation Pattern of Horn Planar Array in Polar form for N=M=40 Elements**



**Figure 24: Radiation Pattern of Horn Planar Array in Rectangular form for N=M=40 Elements**



**Figure 25: Radiation Pattern of Horn Planar Array in Polar form for N=M=80 Elements**



**Figure 26: Radiation Pattern of Horn Planar Array in Rectangular form for N=M=80 Elements**

## CONCLUSIONS

Horn Antennas are used in high frequencies. In this paper, the design and analysis of horn antenna in optimum frequency 5GHz has been described. Horn antenna often has a directional radiation pattern, with a high antenna gain which can range up to 25dB. The directivity, gain are high and low vswr. The width of the aperture in the E & H fields and slant lengths of the aperture in the E & H fields are discussed here. The radiation patterns of pyramidal horn antennas are plotted at  $a_1 = 5.5\lambda$ ,  $b_1 = 2.75\lambda$ ,  $a = 0.5\lambda$  and  $b = 0.25\lambda$ . The number of side lobes is identified from the results.

The beam width is reduced when the length of antenna increased and observed. The array field patterns of both

linear and planar array are plotted and their results are presented in above figures. Using pattern multiplication the horn linear array and horn planar array radiation patterns are also drawn for different values of N and M elements. It is observed that the first side lobe level is -21 dB. The main beam width reduced when the numbers of elements are increased. These are useful in microwave applications.

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## APPENDICES

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